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Research on Diabatic Initialization

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The current four-dimensional meteorological data assimilation schemes employed at forecasting centers are designed to analyze the mass (pressure and temperature) and rotational wind fields accurately, primarily in the middle to higher latitudes. They are deficient in the tropics and in the analysis of irrotational wind and moisture fields. The number of radiosonde water vapor observations is too small to influence the first-guess field of water vapor. The magnitude of irrotational wind component is on the order of observational errors of horizontal wind. Thus, the analyzed irrotational wind and water vapor fields are basically the products of data assimilation models.

The objective of this research project is to contribute to improvement in the synoptic analyses in the tropics for numerical weather prediction and climate research. In addition to a prediction model, four dimensional data assimilation systems have two principal components. One is objective analysis and the other is initialization. Various methods of objective analysis are designed primarily to analyze the mass and rotational wind fields. Methods of initialization are developed to obtain the irrotational wind and its associated vertical velocity field which are balanced with the mass field and free from meteorological noise.

There are essentially three approaches to the problem of initialization: quasi-geostrophic theory, bounded derivative method and nonlinear normal mode method. In the midlatitudes, these approaches generally produce satisfactory results even without diabatic effects for large-scale motions. In the tropics, the situation is quite different from that in the midlatitudes. Because of a small magnitude of the Coriolis parameter and a weak horizontal temperature gradient in the tropics, any method of initialization must incorporate diabatic effects. In fact, we can even say that understanding the problem of *diabatic initialization* is the key to improving the analysis and weather forecasting in the tropics.

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Research accomplishments over the period of July 1989 – June 1990

Although this project did not formally start until January 1990, we include the results of our preliminary work, carried out under the NCAR core program.

Estimation of the uncertainty of daily synoptic analyses

In order to learn where weakness exists in the present objective analysis procedures, in terms of large disagreement between various analyses, Akira Kasahara and Arthur P. Mizzi conducted the intercomparisons of three different FGGE Level IIIb analysis datasets, the *original* ECMWF (European Centre for Medium Range Weather Forecasts), *reanalysis* ECMWF and *reanalysis* NMC (National Meteorological Center, Washington, D.C.). We examined the daily values of large-scale vorticity ζ, divergence δ, temperature T, static stability Γ, vertical motion ω, and diabatic heating rates Q/C_p during the period of 26 January to 11 February, 1979. In addition to the intercomparison statistics which describe systematic differences, spatial coherence and quantitative agreement, equivalent blackbody temperatures observed by the TIROS-N are used to estimate the relative accuracy of vertical motion and diabatic heating rates in the tropics. They have focussed on the following questions: (1) how data agreement changes depending on the scale of motion, considered at spherical harmonic truncations triangular 13 (T13) and 42 (T42); (2) which aspects of analyses are improved by ECMWF and NMC; (3) which aspects of analysis are still considered unsatisfactory; and (4) what further improvement can be made in the analyses. One piece of good news is that the agreement of vorticity at T13 is excellent and that at T42 is still good, indicating the FGGE has succeeded in describing the quasi-rotational state of the atmosphere, even in the tropics. The bad news is that the agreement of divergence at T42 is poor and, similarly, the vertical motion has the least agreement, indicating the need of further improvement in describing the tropical irrotational circulations.

Solution to the spin-up problem of precipitation forecasts

One deficiency with tropical weather forecasts is that numerical models are incapable of producing realistic tropical precipitation rates at the beginning of the model run. This is known as the 'spin-up' problem and is caused, in part, by shortcomings in the initial specification of divergence, moisture and temperature. Diabatic initialization successfully suppresses inertial-gravity waves but it cannot ameliorate the spin-up problem because: (1) The diabatic information is inadequate for tropical initialization. (2) There is no initialization of the moisture field. (3) There is no initialization of the cumulus parameterization scheme. Kasahara and Mizzi, in collaboration with Leo Donner (University of Chicago), made progress in coming to grips with this spin-up problem. They have developed a tropical initialization procedure to augment current diabatic nonlinear normal mode initialization (NNMI) schemes. This procedure attempts to initialize cumulus convection in the tropics and consequently reduce the severity of the spin-up problem; *i.e.*, after initialization the precipitation rates vary realistically with respect to time and space throughout the forecast period. This procedure only adjusts initial fields in the tropics since diabatic NNMI is appropriate for the midlatitudes.

Studies on the relationships between the mass and wind fields and diabatic heating

During the past six years there has been much confusion regarding the utility of diabatic NNMI and other NNMI procedures. Taking advantage of a one-year visit to the Naval Environmental Prediction Research Facility (NEPRF) under the UCAR/NEPRF visiting scientist program, Ronald Errico (1989c) has prepared a technical note entitled *Theory and Application of Normal Mode Initialization.* This report is intended for use in graduate studies and includes extensive sections on why NNMI-type balances exist in models and why the NNMI formalism is useful for describing balance.

Errico (1990) has also performed an extensive analysis of dynamic balance in both the CCM (NCAR Community Climate Model) and the Pennsylvania State University/NCAR Mesoscale Model Version 4 (MM4). To the degree that their physical processes are realistic, the balances which the models establish in their equilibrium states are similar to real atmospheric balances. Therefore, the analyses of these simulated data are useful for determining NNMI implementation strategies. Errico's investigation has focussed on three topics: examination of the temporal characteristics of diabatic heating projected on model gravity waves; determination of the degrees to which individual gravity modes satisfied first order and higher order, diabatic NNMI balance conditions; and an examination of balance on the mesoscale. Results indicate that existing balances are adiabatic and that the degree of balance is more a function of vertical scale rather than horizontal scale.

Focus of current research

Kasahara and Mizzi are preparing a manuscript entitled "Estimates of global analysis differences in daily values produced by two operational centers" for submission to *Mon. Weather Rev.* The paper points out the need of a revolutionary idea for improvement in analyzing the tropical circulations which are diabatically driven.

Kasahara, Mizzi and Donner are preparing a talk entitled "Impact of cumulus initialization upon the spin-up of precipitation forecasts in the tropics" to present at the WMO International Symposium on Assimilation of Observations in Meteorology and Oceanography, to be held at Clermont-Ferrand, France, 9–13 July 1990. A manuscript of the same title is also being prepared for publication to *Mon. Weather Rev.*

Plans for next year

Improvement in the analyses of vertical velocity and water vapor fields in the tropics

We plan to apply the findings from our solution to the precipitation spin-up problem to incorporate into the analyses of vertical velocity and water vapor fields, particularly in the tropics. As we mentioned, a revolutionary idea is needed to improve the analyses of irrotational wind and water vapor. In fact, it has been noted that now satellite temperature and humidity soundings (SATEMs) are no longer giving significant impact on analysis and forecasts in the northern hemisphere, due primarily to large errors of SATEM data and to improvement in the dynamical models used for data assimilation. We plan to use satellite radiometric imagery data, which have not been incorporated in operational analysis systems, to identify convective activity in the tropics and as proxy data for the total convective heating rates. We also need the vertically integrated total precipitable water as observed, for example, by Special Sensor Microwave/Imager (SSM/I). In this respect, we plan to cooperate closely with Pete Robertson, MSFC.

Investigation of the role of diabatic heating in the dynamical balance of the atmosphere

There are several outstanding issues related to the problem of nonlinear normal mode initialization (NNMI), particularly in its application to the tropical circulations. Because the tropical circulations are influenced by a smaller magnitude of the Coriolis parameter f and a larger magnitude of the Rossby parameter β, in addition to relatively strong diabatic effects, the question of the dynamical balance between the mass and wind fields in the tropics has been difficult to answer. The NNMI methodology has been very helpful in this connection, but because of its handling of spectral space variables understanding of the balance state has been rather difficult. Another hurdle exists in understanding the role of diabatic heating effects in describing the dynamical balance of the tropical circulations. Because the tropical circulations are characterized by small equivalent depths, the natural frequencies of normal modes representing the tropical motions are relatively small and it is difficult to distinguish between meteorologically significant motions, sometime referred to as oscillations of the second kind (such as Rossby waves) and inertia-gravity motions, often referred to as meteorological noise. We will investigate the role of diabatic heating in the dynamical balance of the tropical atmosphere through various avenues of model research. For example, we will revisit the question of the relationship between the NNMI and the bounded derivative method.

List of Publications

Errico, R. M., 1989a: The forcing of gravitational normal modes by convective heating. *Mon. Weather Rev.*, **117**, 2734–2752.

Errico, R. M., 1989b: The degree of Machenhauer balance in a climate model. *Mon. Weather Rev.*, **117**, 2723–2733.

Errico, R. M., 1989c: *Theory and Application of Nonlinear Normal Mode Initialization.* NCAR Technical Note, NCAR/TN-344+IA, 145 pp.

Errico, R. M., 1990: An analysis of dynamic balance in a mesoscale model. *Mon. Weather Rev.*, **118**, 558–572.

Kasahara, A., 1990: Transient response of planetary waves to tropical heating: Role of baroclinic instability. *J. Atmos. Sci.*, submitted.

Kasahara, A. and K. Tamiya, 1989: *The spin-up of precipitation forecasts with a global atmospheric model.* JMA/NPD Technical Report, Japan Meteorological Agency, 62 pp.

Kasahara, A., and H. L. Tanaka, 1989: Application of vertical normal mode expansion to problems of baroclinic instability. *J. Atmos. Sci.*, **46**, 489–510.

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Xue, Y., K.-N. Liou and A. Kasahara, 1989: Investigation of the biogeophysical feedback on the African climate using a two-dimensional model. *J. Climatol.*, **3**, 337–352.